Defense Technical Information Center Compilation Part Notice

ADP010929

TITLE: Stabilization of Chaotic Amplitude Fluctuations in Multimode, Intracavity Ddoubled Solid-State Lasers

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Paradigms of Complexity. Fractals and Structures in the Sciences

To order the complete compilation report, use: ADA392358

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, ect. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:

ADP010895 thru ADP010929

Stabilization of chaotic amplitude fluctuations in multimode, intracavity-doubled solid-state lasers [a].

Monika E. Pietrzyk
Institute of Solid State Physics and Theoretical Optics
Friedrich-Schiller-Universität Jena
Max-Wien-Platz 1, 07-743 Jena, Germany
tel: (+49-3641) 947-174, fax: (+49-3641) 947-152
e-mail: p8pimo@rz.uni-jena.de, mpietrz@ippt.gov.pl

Intracavity doubled solid state lasers based on Nd-doped crystals are efficient and compact sources of coherent visible optical radiation. When such lasers operate in three or more longitudinal cavity modes, irregular fluctuations of the output intensity may occur. This behavior, referred to as the green problem, has been reported for the first time by Baer [1]. He found that these instabilities arise from a coupling of the longitudinal modes of the laser by sum-frequency generation, which occur in the intracavity-doubling crystal. When the laser does not contain the nonlinear crystal or when it operates in a single longitudinal mode, its output is stable. In the case of two oscillating longitudinal modes, output intensity of the laser is stable only for small values of nonlinearity, otherwise both modes tend to pulse on and off out of phase with each other [1]. When the number of lasing modes is larger than two, the laser can exhibit, depending on the parameters describing it, various behaviors like: aniphase dynamics [2], [3], clustering [1], grouping [4] and chaotic dynamics [5].

The main goal of this communication is to study the possibilities of a stabilization of large amplitude fluctuations in such a laser, i.e., an intracavity-doubled Nd:YAG laser. The analysis is based on the Baer-type rate equations [1]

$$\tau_{c1}\frac{\partial I(p,t)}{\partial t} = I(p,t)\left(-\alpha_p + G(p,t) - \epsilon I(p,t) - 2\epsilon\sum_{q\neq p} I(q,t)\right), \tag{1a}$$

$$\tau_f\frac{\partial G(p,t)}{\partial t} = G_{ap} - G(p,t)\left(1+\beta(p,p)I(p,t) + \sum_{q\neq p}\beta(p,q)I(q,t)\right), \tag{1b}$$

$$p, q = 1, ..., N,$$

where N is the number of longitudinal modes; τ_c and τ_f are the cavity round trip time and the fluorescence lifetime of the Nd^{+3} ion, respectively; $I(p,t)$ and $G(p,t)$ are, respectively, the intensity and gain associated with the p-th longitudinal mode; α_p is the cavity loss parameter for the p-th mode; G_{ap} is the small signal gain; $\beta(p,p)$ is the self-saturation coefficient in the active medium; $\beta(p,q)$ is the parameter describing the cross-saturation between two longitudinal modes, p and q. The parameter ϵ is a nonlinear coefficient whose value depends on properties of the nonlinear crystal and it describes the conversion efficiency of the fundamental

[a] **Key words:** Chaos in laser cavities; Multimode, intracavity-doubled solid-state lasers; Baer-type rate equations

intensity into the doubled intensity. The terms $\epsilon I(p,t)^2$ and $\epsilon I(p,t)I(q,t)$ in Eq. (1a) account for the loss in the intensity of the fundamental frequency through second harmonic generation and through sum-frequency generation, respectively, and they provides a nonlinear loss mechanism that globally couples the longitudinal modes, i.e. each lasing mode is coupled to all other lasing modes [2]. A comparable amount of global coupling occurring in the set of Eq. (1) is introduced by the cross-saturation coefficient, $\beta I_k G_k$. We use the approximation that the cross-saturation coefficient is constant for all modes, $\beta(p,q) = \bar{\beta}$, where $\bar{\beta} = \frac{2}{3}\beta_0$ or $\bar{\beta} = \frac{1}{3}\beta_0$, where $\beta_0 = 0.06$ is a scalling parameter. We assume also that the losses and the small signal gains are the same for all modes, i.e. $\alpha_p = \alpha_q = \alpha$, $G_{ap} = G_{aq} = G_a$, where $p,q = 1,...,N$. Other parameters describing the system we have chosen in such a way that they can describe a real experimental configuration of the laser, i.e., $\tau_{c1} = 10\,[ns]$, $\tau_f = 0.24[ms]$, $\alpha = 0.015$, $\gamma = 0.12$. The number of longitudinal modes, $N = 1,...,250$, and the strength of nonlinearity, $\epsilon = 10^{-7} \div 10^{-3}$, are not fixed and they vary in the analysis.

First, we analyze numerically the stabilization of the laser radiation by an increase of the number of longitudinal modes, proposed in [2]. We observe that the theoretically obtained [3] linear dependence of the minimal number of modes, which are needed to stabilize the laser output, on the strength of nonlinearity agree with the numerical solutions only in the case of sufficiently small nonlinearity. For large nonlinearity the minimal number of modes obtained by the numerical simulations is larger than the number which follows from the theoretical predictions. It is caused by a strong cancellation of modes during the evolution. For very large nonlinearity this cancellation is so strong that only few modes remain (even when there are initial 250 oscillating modes). Therefore, a large number of simultaneously oscillating longitudinal modes cannot be achieved in this case.

However, the problem of the stabilization of the laser output can be solved in another way, namely, by an increase of the strength of nonlinearity, which leads to very strong competition between the modes, so that during the evolution all of them, besides a single one, are canceled. As a consequence, a steady-state solution, which is stable against small perturbations, arises.

This way of stabilization, achieved by forcing the laser to operate in one-mode regime, is similar to other approaches presented in the literature, where the stabilization is obtained by inserting into the laser cavity an additional element like, for example, an etalon [1] or a birefringent crystal. However, this proposed method seems to be a better solution, since no additional element is needed and the output intensity of the doubled frequency is larger (it increases with the increasing of the strength of nonlinearity).

References

1. T. Baer, J. Opt. Soc. Am. B **3**, 1175 (1986).
2. G. E. James *et al.*, Opt. Lett. **15**, 1141 (1990).
3. J.-Y. Wang and P. Mandel, Phys. Rev. A **48**, 671 (1993).
4. K. Otsuka, Y. sato, and J. L. Chern, Phys. Rev. E **56**, 4765 (1997).
5. M. E. Pietrzyk and M. B. Danailov, preprint of the ICTP (the Abdus Salam International Centre for Theoretical Physics), Trieste, Italy, **IC/98/235** .